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Review

Review on Aquatic Weeds as Potential Source for Compost Production to Meet Sustainable Plant Nutrient Management Needs

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Abstract: As a result of the increase in agricultural production and environmental pollution, waste management and disposal are becoming vital. Proper treatments, such as converting abundant bio-mass wastes into beneficial materials, might mitigate the negative effects and convert waste into reusable resources. Aquatic weeds are a significant concern in the majority of water bodies. Their quick growth, rapid ecological adaptations, and lack of natural enemies make these plants invasive, problematic, and challenging to manage over time. Although there are many methods to manage aquatic weeds, composting has been identified as one of the easily adapted and eco-friendly methods for transferring nutrients to the cropping cycle. Their short life cycle, higher biomass yield, higher nutrient compositions, and allelopathic and phytoremediation properties confirm their suitability as raw materials for composting. Most aquatic ecosystems can be maintained in optimum conditions while facilitating maximum benefits for life by identifying and developing proper composting techniques. Studying the ecology and morphological features of aquatic weeds is essential for this purpose. This is an overview of identifying the potential of aquatic weeds as a source of composting, targeting sustainable plant nutrient management while managing weeds.

Keywords: agriculture; agricultural waste management; allelopathic effect; invasive species; phytoremediation

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1. Introduction

Modern conventional high-input agriculture has caused many problems in all agricultural ecosystems, even in nature. This happens mainly due to low soil organic matter content, unbalanced soil nutrient levels, inappropriate irrigation, and higher biomass waste generation, resulting in the depletion of arable lands and crop yield [1–3]. Therefore, effective soil nutrient management with limited resources available is essential for maximizing crop output to satisfy the growing food demand in the twenty-first century.

Composting is one of the eco-friendly approaches for recycling bio-waste productively and cost-effectively [2]. Composting is a natural biological decomposition process that converts different types of organic waste into beneficial organic products under controlled conditions [4]. End-products such as humus, biomass, carbon dioxide, and heat are produced during the composting process [5]. It is an aerobic process controlled by various decomposing agents, including bacteria, fungi, and actinomycetes, which vary with the different stages of compost formation [5]. Quality raw materials, including nutrients such as carbon (C), nitrogen (N), phosphorus (P), and potassium (K); supportive carbon/nitrogen (C/N) ratio; moisture content; natural qualities (porosity, particle size, and bulk density); adequate oxygen supply; and conditions of the composting process such as temperature and pH changes should be present for better growth of micro-communities and thus fast and high-quality composting production [5–8]. Furthermore, for a sufficient nutritional balance during composting, the C/N ratio of primary organic waste should be between 25 and 35 under optimal conditions [9].

Depending on farmers' preferences and availability, different raw materials such as municipal organic waste [10]; sewage sludge [11]; all kinds of farm wastes (garden debris, weed residues, stalks and stems, fallen leaves, pruning parts, chaff, fodder, and leftovers) [12]; livestock (buffalo, cow, goat, and swine) and poultry manure [13,14]; oil palm wastage, such as effluent of the oil palm mill; empty fruit bunches; and immature fallen fruits [4] are used for composting.

Aquatic weeds have also been used as a raw material for composting due to their rapid establishment and growth, which has caused the degradation of aquatic ecosystems [15]. Aquatic weeds are the plants that complete their life cycle at either the water–land interface or in the water environment, hence interfering with ecosystem processes [16]. Their rapid growth, fast spread, fast ecological adaptations, and lack of natural enemies will make these plants invasive, problematic, and difficult to manage over time [17,18]. Most of the aquatic weeds are exotic species and have been introduced for ornamental and landscaping purposes [15].

Depending on the mode of adaptation and nature of the harm and control, these plants can be classified into three groups: floating, submerged, and emergent (Figure 1) [19,20]. However, this is not a unique classification. Some common aquatic weeds found in the world are listed in Table 1 [19,21].

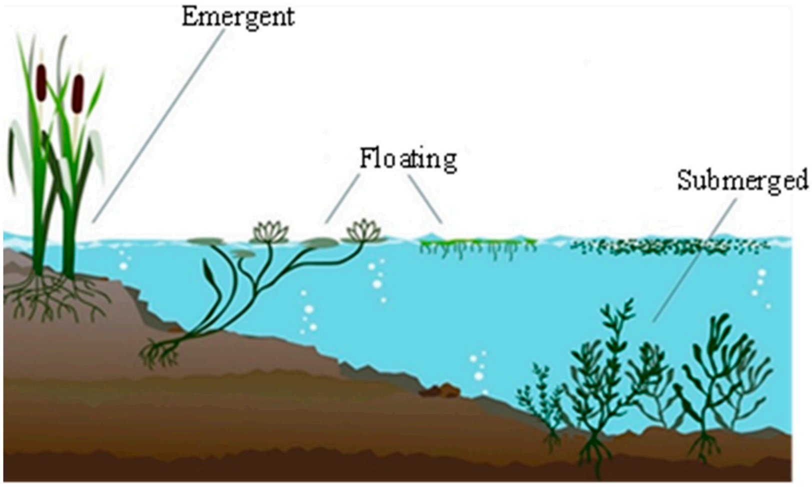

Figure 1. Three types of aquatic weeds.

Table 1. Common aquatic weeds in the world [19,21–23].

Plant Type	Botanical Name	Family
Floating	*Azolla* spp.	Azollaceae
	Eichhornia crassipes	Pontederiaceae
	Hydrilla verticillata	Hydrocharitaceae
	Lemna spp.	Lemnaceae
	Pistia stratiotes	Araceae
	Salvinia molesta	Salviniaceae
Submersed	*Cabomba caroliniana*	Cabombaceae
	Ceratophyllum demersum	Ceratophyllaceae
	Chara spp.	Characeae
	Crassula helmsii	Crassulaceae
	Egeria spp.	Hydrocharitaceae
	Lagarosiphon major	Hydrocharitaceae
	Nitella spp.	Characeae
	Potamogeton spp.	Potamogetonaceae
	Utricularia spp.	Lentibulariaceae
	Vallisneria spp.	Hydrocharitaceae

Table 1. *Cont.*

Plant Type	Botanical Name	Family
Emersed	*Brachiaria* spp.	Poaceae
	Ipomoea spp.	Convolvulaceae
	Limnocharis flava	Limnocharitaceae
	Ludwigia spp.	Onagraceae
	Lythrum salicaria	Lythraceae
	Monochoria spp.	Pontederiaceae
	Myriophyllum spp.	Haloragaceae
	Nelumbo nucifera	Nymphaeaceae
	Nuphar luteum (*Nyphaea* spp.)	Nymphaeaceae
	Nymphaea stellata	Nymphaeaceae
	Phragmites karka	Poaceae
	Polygonum spp.	Polygonaceae
	Sagittaria spp.	Alismataceae
	Scirpus spp.	Cyperaceae
	Spartina spp.	Poaceae
	Sphenoclea zeylanica	Sphenocleaceae
	Typha spp.	Typhaceae
	Vossia cuspidata	Poaceae
Wetland tree	*Melaleuca quinquenervia*	Myrtaceae
Mat-forming	*Alternanthera philoxeroides*	Amaranthaceae

Sri Lanka is an island that contains a large extent of fresh-water reservoirs. Approximately 23.3% of agricultural lands are cultivated with those resources in both of the two major cropping seasons [24]. As shown by Kariyawasam et al., the aquatic invasive alien plant community in the local tank cascade system has been spread over the past few decade creating many difficulties ecologically, environmentally, and economically [22]. Variations in environmental factors, anthropogenic activities, and ecological factors change the abundance of such aquatic plants from time to time. A few locally abundant aquatic invasive weed species have been listed in Figure 2.

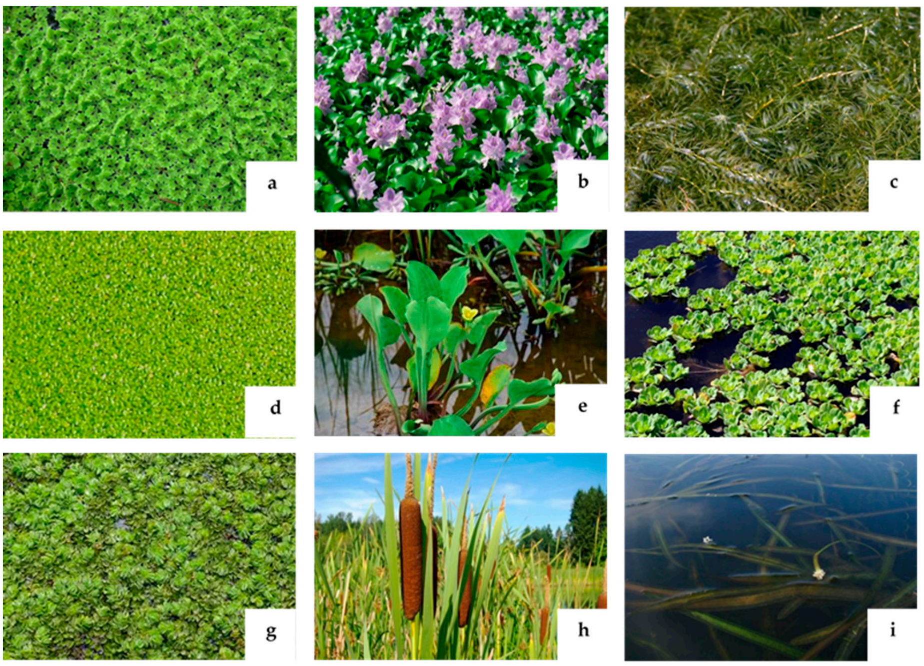

Figure 2. Common aquatic weeds found in Sri Lankan aquatic ecosystems: (**a**) *Azolla* spp.; (**b**) *Eichhornia crassipes*; (**c**) *Hydrilla verticillata*; (**d**) *Lemna* spp.; (**e**) *Limnocharis flava*; (**f**) *Pistia* spp.; (**g**) *Salvinia molesta*; (**h**) *Typha* spp.; (**i**) *Vallisneria* spp. [22,24,25].

The majority of aquatic weeds pose risks to agricultural lands, aquatic habitats, and natural and forest ecosystems. A few of them can be listed as follows:

1. Interruptions to hydropower generation due to the reduction of water levels in water bodies, siltation, the inefficiency of related machines and equipment (such as turbines), and high maintenance costs [23,26].
2. Disturbance in navigation thereby influencing fisheries and water recreation [21].
3. Impact on the life of aquatic organisms such as fish, submerged plants, and phytoplankton [27]. That is mainly due to interrupting the photosynthesis of aquatic flora (by limiting light penetration into deep water layers) and changing the oxygen: carbon dioxide gas balance [23,28].
4. Blocking irrigation and water channels leading to flooding and bank erosion incidences [19].
5. Noxious aquatic plants in water bodies reducing irrigation water for agriculture as it increases water loss by evapotranspiration [27].
6. Influence on drinking and other household consumption, health-related issues such as insect-borne (primarily mosquito-infested) and poisonous incidences (plants, snakes, insects, and fish) of water bodies on the surrounding human community [29].
7. Reduction of aesthetic appearance of water bodies as a result of eutrophication and foul smell [30].
8. Economic losses related to social, ecological, and policy issues occurring mainly due to the eutrophication phenomenon in water bodies. This may cause the increasing purifying cost of polluted water and negative impacts on tourism [31].
9. Challenges with the sustainability of aquatic ecosystems.

The probability of the successful control of aquatic weeds is inversely related to the size of the aquatic ecosystem, and adapting intergraded weed management will be more effective than a single weed control method [32]. Controlling these plants needs more attention due to their higher growth rate, dispersion ability, and capacity for the formation of resistance structures for survival. The commonly used control methods are mentioned below.

1.1. Preventive Management

The spread and further introduction of aquatic weeds can be avoided by following rules and regulations on plant trades, plant and animal transportation, quarantine, and proper construction and maintenance of water bodies [33].

1.2. Manual and Mechanical Management

This method is more labor-intensive and time-consuming compared to other methods [34]. Reduction in water levels in water bodies may influence the growth of submerged and floating aquatic weeds due to changing in the nutrient composition of the water [35]. Introducing barriers like booms and cables in the water channels, manual removal of weeds using rakes and fine-meshed nets, and mechanical removal using tractors and excavators are the common manual and mechanical methods used to manage aquatic weeds [36]. With advanced technology, types of equipment like autonomous rotary-wing unmanned air vehicles have been developed for easy handling [37]. Manual and mechanical removal of submerged and floating aquatic weeds such as *Hydrilla verticillata* and *Egeria* spp. can lead to canopy fragmentation resulting in subsequent dispersal and an increase in weed population [38].

1.3. Ecological Aquatic Weed Management

These plants are essential to the aquatic ecosystem as they offer the majority of the food, nutrients, and habitat for aquatic life while regulating the concentrations of dissolved gases in the water. As a result, the unexpected removal of a significant amount of these could disrupt ecosystem services. Therefore, understanding the importance of aquatic weeds in a particular aquatic environment, and studying the ecological strategies, adaptations of the plants, and environmental consequences after removing them from that environment are important before adapting weed management strategies [39].

1.4. Chemical Management

Selecting the most suitable herbicides which are specific to aquatic weeds and applying them at the correct time with the recommended dose will control the aquatic weeds effectively without harming their ecosystems [16]. Some components (ingredients and/or surfactants) in such herbicides can be toxic to beneficial aquatic organisms and terrestrial biological controlling agents [40]. The toxicity of diquat, glyphosate, and glyphosate-trimesium chemicals (which is used for controlling *Eichhornia crassipes*) on aquatic insects such as *Eccritotarsus catarinensis* and *Neochetina eichhorniae* had been proven by previous literature [40].

1.5. Biological Management

Since 99% of aquatic weeds are new entries to the ecosystems, natural biological controlling agents cannot be found in existing environments [41]. Therefore, specific controlling agents for particular weeds should be identified and transported after analyzing their negative effects on the ecosystems as well [32]. In some areas, this method is considered as a slow and insufficient method for short-term benefits [42].

Potential biological control agents are fungal species such as *Fusarium* spp. for *Egeria densa*, *Cercospora pistiae* for *Pistia stratiotes*, *Phaeoramularia* spp. and *Phoma* spp. for *Echinochloa polystachya* and *Paspalum repens* [43], insects such as *Agasicles hygrophila* and *Vogtia malloi* for *Alternanthera philoxeroides*, *Bagous affinis* Hustache and *Hydrellia pakistanae* Deonier for *Hydrilla verticillata*, *Stenopelmus rufinasus* for *Azolla* spp., *Cornops aquaticum* and *Eccritotarsus catarinensis* for *Eichhornia crassipes* [34,44], and fish species such as *Ctenopharyngodon idellus* and *Cyprinus carpio* for controlling a variety of weeds, especially Filamentous algae [45].

1.6. Aquatic Weed Management through Utilization

Despite the fact that aquatic plants have become invasive in some regions of the world, certain weeds have directly led to socioeconomic livelihood in other areas. Some aquatic weeds have a greater potential to be used as a bio-fertilizer due to their allelopathic behaviors [46] and a mulching material for supplying plant nutrients and organic matter, retaining soil moisture, and increasing soil microbial population [47]. Its higher cellulose, hemicellulose, and low lignin content can easily be used for making low-cost bags, paper plates, paper boards, and decorative paper [48]. Moreover, aquatic weeds are potential raw materials for producing biogas and thereby generating electricity [49]. *Azolla* spp. is considered as a feed supplement for livestock, poultry, and aquaculture farming due to its high nutritional value, especially with favorable amino acids and higher protein content [50,51]. Other than the ornamental value, free radical scavenging pigments in *Nymphaea pubescens* extract have a medicinal value that can be used for treating melanoma skin cancers [52]. *Eichhornia crassipes* is an ornamental plant and is also popular as a phytoremediation plant, a source of biomass energy, and a source of raw materials for animal feed, construction, handicraft, paper, and board making [53]. *Pistia stratiotes* oil extract is good medicine, especially for worm infections, asthma, and skin disease, while leaves and roots are excellent sources of antioxidants [54]. Other than that, every part of *Nelumbo nucifera,* including leaves, rhizomes, seeds, and flowers, have been involved with traditional human livelihood as a part of the human diet, ayurvedic medicine, pharmaceuticals, and also landscaping [55].

Controlling aquatic weeds is very difficult in developing countries such as Sri Lanka due to limited resources. As a result of that, several types of aquatic weed species have grown at an alarming rate, causing a disturbance in nature and agriculture in Sri Lanka. The ultimate aim of this work is to evaluate the feasibility of aquatic weeds to be used as a raw material for compost production to meet the requirements in sustainable plant nutrient management in the local context. Aquatic weed management will thereby be more effective in terms of the agriculture and ecosystem level.

2. Aquatic Weeds as a Potential Raw Material in Composting

According to the literature, composting is one of the best methods for transferring nutrients in aquatic weeds into crop production [23,56]. Its short life cycle with higher biomass yield confirms its continuous availability as raw materials for composting [57]. Aquatic weeds are known as excellent sources of minerals, vitamins, proteins, and carbohydrates that are beneficial for plant health (Table 2). In addition, its allelopathic action, phytoremediation properties, and lower technology involvement also point out the suitability of aquatic weeds for composting. Even though most aquatic plants can be applied as green manure, with the process of composting, more nutrients can be available for plants [16].

Composting agents use carbon as a source of energy, which causes them to break down complex carbon compounds such as cellulose, hemicellulose, and lignin into simpler forms, leaving higher organic matter losses [58,59]. As shown by Gusain et al., *Pistia* spp. reduces its total organic carbon content from 461 g/kg to 449.87 g/kg through composting. The losses happen mainly as carbon dioxide gas. When *Salvinia molesta*, *Eichhornia crassipes*, and *Lagenandra toxicaria* are vermicomposted with cow dung, the resulting organic carbon contents (at 70% of moisture content) were 8.37%, 8.24%, and 13.21%, respectively, whereas the *Gliricidia* and grass mixture produced 9.54% in 70% of moistened samples [57]. Concentrations of the primary nutrients can be increased by composting (Figure 3). The reasons for increasing total kjeldahl nitrogen content (TKN) in prepared compost may include: (1) the nourished activities of earthworms, with the excreting nitrogen sources (nitrogenous excretory products, mucus, body fluids, and various enzymes) and their feeding mechanisms; (2) the conversion of ammonium nitrogen into nitrates in the vermicomposting process; (3) the mineralization of organic materials; and (4) the conversion of proteins in the aquatic weeds [56]. These fluctuations lead to a decrease in the C/N ratio, demonstrating the compost's suitability in terms of stability and maturity [59,60]. Prior research has found that compost materials with a C/N ratio of 20 to 25 produce the greatest results because a greater C/N ratio delays the degradation of raw materials [59]. Higher phosphorous content (TP) in prepared compost than weed sediments may result due to earthworm gut reactions at the production process. Phosphorus-solubilizing micro-organisms will help mineralize and increase the availability of phosphorus as different phosphate components. Mainly, the group of bacteria known as "diazotrophic bacteria" (for example, *Pseudomonas* spp., *Burkholderia* spp., *Agrobacterium* spp., *Azotobacter* spp., and *Erwinia* spp.) have been identified as phosphorus-solubilizing micro-organisms [61]. It not only increases the end phosphorus content, but it also activates the phosphorus recycling process. The least amount of phosphorus can be leached down the compost pile [58]. A slight increase in potassium concentration (TK) in the end product could be observed due to releasing acids that can convert insoluble potassium into a plant-available form during composting by micro-organisms [56].

Most aquatic weeds absorb toxic metals from the surrounding environment [62]. Therefore, it is important to monitor the potentially toxic metal contents to avoid the bioavailability risks. Standards and guidelines for that are promulgated by a variety of agencies in worldwide [63]. As mentioned in the previous literature, the majority of potentially toxic metal concentrations are well within accepted standards which are stated by the Colombian Technical Norms (NTC) 5167/04 and the standard of the Fertilizer Control Order 1985 [56,64]. In the local context of the Sri Lankan Standards Institution, Sri Lanka had placed important specifications on toxic elements for compost made from raw materials of organic origin to maintain the quality. A comparison of maximum permissible limits of potentially toxic metal elements in compost has been given in Table 2.

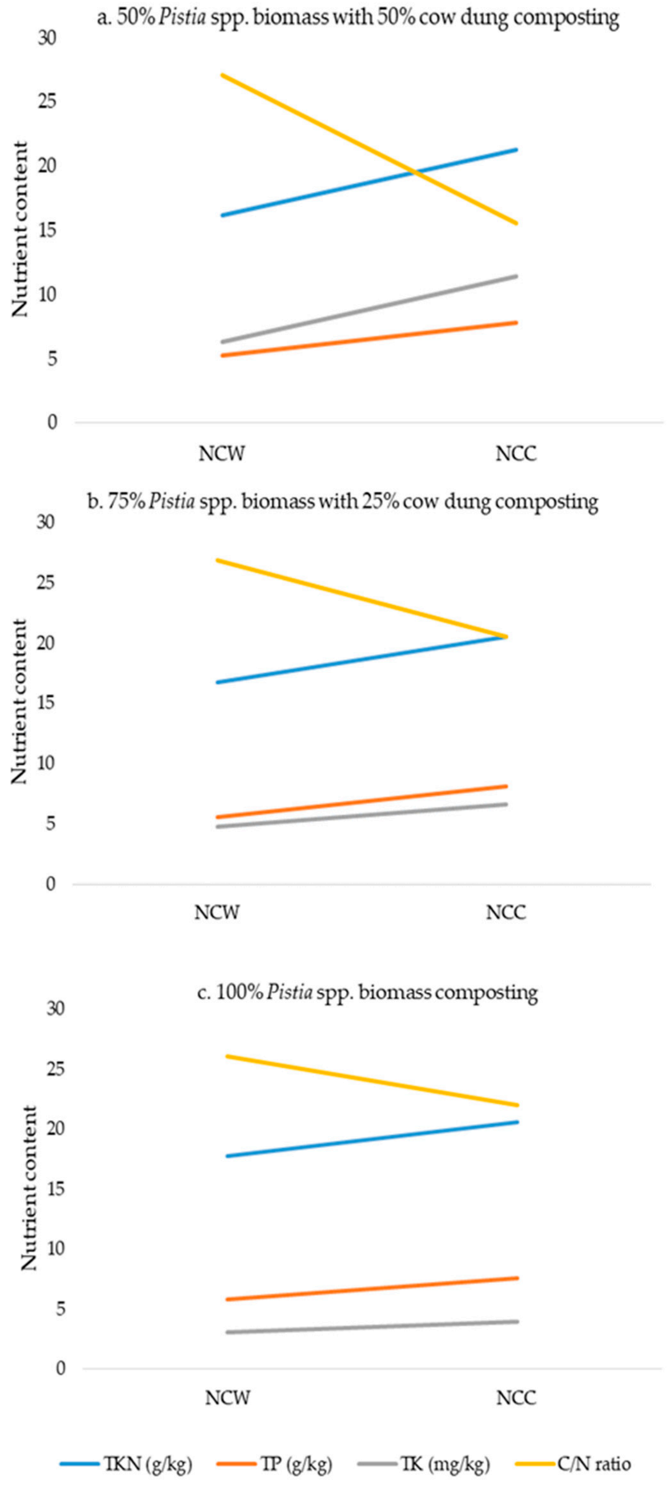

Figure 3. Chemical analysis of initial and composted waste mixtures produced by (**a**) 50% *Pistia* spp. biomass and 50% cow dung composting; (**b**) 75% *Pistia* spp. biomass and 25% cow dung composting; and (**c**) 100% *Pistia* spp. biomass composting [59]. Note: NCW—Nutrient content of weed sediment, NCC—Nutrient content of prepared compost. Methods which are used to measure TKN are the micro-kjeldahl digestion method, the method of ascolbic acid-reduced molybdophosphoric acid method for TP, and the flame photometer (Systronic 128) method for TK in Dehradun, India.

Table 2. The maximum limits for potentially toxic elements promulgated by different agencies [63,65].

Potentially Toxic Element	EU Range (mg/kg)	USA Biosolids (mg/kg)	Sri Lankan Standards (SLS) (mg/kg Dry Basis, AOAC Testing Method)
Cadmium (Cd)	0.7–10	39	1.5
Chromium (Cr)	70–200	1200	50
Mercury (Hg)	0.7–10	17	0.5
Nickel (Ni)	20–200	420	40
Lead (Pb)	70–1000	300	30

Most aquatic weeds have a considerable positive chance to be a good source of nutrients in the local context and this had been confirmed by several works in the literature [57,63,66]. The dynamic interaction between bacteria and earthworms affects the fate of heavy metals and alters their concentrations. Microbes present in the gut of the earthworms have good potential to detoxify, absorb, and accumulate the heavy metals from the raw material leaving a low concentration in compost and high concentration in earthworm bodies [56]. Later, those earthworms can be removed from the content, especially in vermicomposting. In contrast, fungi-like organisms and physiochemical processes such as oxidation, formation of organometallic complexes, and solubilization, as well as naturally occurring zeolites/hydrated alum-inosilicate minerals, would contribute to the changing bioavailability of potentially toxic metal concentrations during composting [67]. The addition of lime, sodium sulfide, bamboo charcoal, bamboo vinegar, or red-mud also has good potential to alter the forms of heavy metals and their bioavailability. One can see a slight fluctuation of concentrations of nickel, cadmium, molybdenum, cobalt, barium, and chromium while increasing the concentrations of zinc, lead, manganese, copper, and lithium in prepared vermicompost compared to initial substrates [56]. Milojkovic et al. introduced a "low-cost biosorbent" method with *Myriophyllum spicatum* L., which showed a lower metal absorption potential for lead(+2), copper(+2), cadmium(+2), and nickel(+2) ions compared to normal composting techniques [68]. Additionally, blending various source materials can alter the risk of bioavailability associated with aquatic weeds (Table 3). It changes the nutrient content, especially potentially toxic metal concentrations as well. Furthermore, considering previous research, we are able to confirm that the performance of aquatic weeds is same as other types of organic waste (Table 4).

Table 3. Variation of potentially toxic metal concentration with different raw material mixing ratios [66].

Potentially Toxic Metals (mg/kg Dry Basis)	Different Compost Mixing Methods						
	50% WH + 25% DLL + 25% CM	50% WH + 45% DLL + 5% WA	50% WH + 45% DLL + 5% ERP	50% WH + 50% DLL	50% WH + 25% DLL + 5% ERP + 5% WA + 15% SLP	50% WH + 25% DLL + 15% CM + 5% ERP + 5% WA	100% WH
Cu	18.5 ± 0.14	13.83 ± 0.18	8.28 ± 0.08	6.44 ± 0.14	5.71 ± 0.08	17.24 ± 0.38	14.6 ± 0.0
Cd	-	-	-	-	-	-	-
Pb	19.59 ± 0.93	6.74 ± 0.26	10.58 ± 0.30	5.78 ± 0.51	5.10 ± 0.48	18.34 ± 0.13	-
Zn	25.16 ± 0.16	31.43 ± 0.70	5.77 ± 0.02	15.97 ± 0.25	26.51 ± 0.32	21.93 ± 0.19	32.47 ± 0.29
Ni	-	-	-	-	-	-	-
As	1.24 ± 0.03	0.28 ± 0.01	1.0 ± 0.05	0.28 ± 0.02	0.21 ± 0.03	1.35 ± 0.04	0.79 ± 0.01

Note: WH—water hyacinth, DLL—dry leaf litter, CM—cattle manure, WA—wood ash, ERP—Eppawala rock phosphate, SPL—spent poultry litter.

Table 4. Comparison of different chemical properties in different compost materials from various raw materials [65,66,69].

Organic Waste Category	Main Ingredients	pH	Electrical Conductivity (dS m^{-1})
Vegetal Residue	Cucumber and zucchini crop residues	9.18	8.48
	Cucumber and zucchini crop residues	8.08	17.36
	Pepper crop residues	9.68	9.97
Municipal Solid Waste	Different sources	8.66	4.97
		7.50	5.58
		6.00	10.29
Agri-food Waste	Citric sludge and palm tree pruning (1:3 *v*/*v*)	6.64	7.24
	Cull tomatoes and tomato plant (stalks and leaves)	7.83	5.1
	Citric sludge, pig slurry, and pruning wastes (mainly palm tree) (3:1:1.5 *v*/*v*)	6.67	2.72
Water hyacinth	50% water hyacinth, 25% cattle manure, 25% dry leaf litter	8.50	4.78
	50% water hyacinth, 45% cattle manure, 5% Eppawala rock phosphate	7.30	1.59
	50% water hyacinth, 25% cattle manure, 15% dry leaf litter, 5% Eppawala rock phosphate, 5% wood ash	7.15	3.49
	100% water hyacinth	7.60	5.28
Requirement set by Sri Lankan Standards Institution		6.5–8.5	4.0

Note: pH and EC of vegetal residue, municipal solid waste, and agri-food waste are measured in a 1:10 (*w*/*v*) (compost: water extract) solution. pH of water hyacinth is determined in a 1:2.5 *w*/*v* solution, and 1:5 *w*/*v* is for determining EC.

Additionally, aquatic weed compost has a greater capacity of making nutrients available for plants and soil rehabilitation. As an example, the potential of *Eichhornia crassipes* compost to rehabilitate the salt-affected soil had been identified by Ahmed et al. [70]. According to these results, part of the chemical requirement (gypsum fertilizer) could be easily cut off with these nutrient-rich compost materials, saving the farmers' wealth as well as environmental health (Table 5).

Table 5. Effect of *Eichhornia crassipes* compost and gypsum on rice and wheat yield [70].

Treatment	Rice Yield (t ha^{-1})	Wheat Yield (t ha^{-1})
Control (no fertilizer application)	1.85	1.52
Application of 100% Gypsum requirement	3.64	3.53
Application of 50% Gypsum requirement with 10 t ha^{-1} *Eichhornia crassipes* compost	3.71	3.58
Application of 10 t ha^{-1} *Eichhornia crassipes* compost	2.44	2.68

Dhadse et al. experimented with investigating the effect of different vermicompost mixtures prepared from different aquatic weeds (*Hydrilla verticilata* (L.f.) Royle., *Ceratophyllum demursum* L., *Nelumbo nucifera* Gaerth., *Ludwigia palustris* L., *Pistia stratioles* L., and *Eicchornia crassipis* Mart.) on the plant growth [56]. All the vermicompost mixtures had shown better plant height, initiation of new leaves, and maturing of exiting leaves compared to soil, indicating their nutrient richness for plant growth and development. This will indicate the suitability of aquatic weed composting as a soil amendment.

3. Methods for Compost Production with Aquatic Weeds

Different composting techniques can effectively transfer many aquatic weeds into valuable manure. Diverse composting processes for different source materials have been developed in various regions of the world, employing newer technology to suit crop requirements while considering local concerns and needs [12,71] as follows:

1. Wind-row methods (turned wind-rows, passively aerated wind-rows, and aerated static pile)
2. In-vessel composting methods (bin composting, passively aerated bin composting, rectangular agitated beds, silos, rotating drums, transportable containers)
3. Traditional methods (anaerobic composting, aerobic composting through passive aeration/static composting)
4. Rapid methods (aerobic high-temperature composting, aerobic high-temperature composting with inoculation, IBS rapid composting)
5. Vermicomposting methods

All the above-mentioned composting methods may not be suitable for composting with aquatic weeds. As examples, biodynamic fortified composting and microbe mediated composting are suited Dal weeds [72], and vermicomposting is suitable for *Salvinia molesta*, *Eichhornia crassipes* and *Lagenandra toxicaria* [57] can be shown. Figures 4 and 5 explain the effect of the different composting methods on *Limnocharis flava* (L.) Buchenau for its recovery percentage and number of days taken for quality compost production. It explains the importance of selecting the proper composting method, as it changes the final yield in terms of quality and quantity. As described in Figure 4, the maximum recovery % or weight of compost gained from unit biomass weight is higher in vermicomposting compared with other composting methods. Considerably, *Limnocharis flava* (L.) Buchenau can be converted into a nutrient-rich amendment with a shorter period than normal composting techniques (Figure 5).

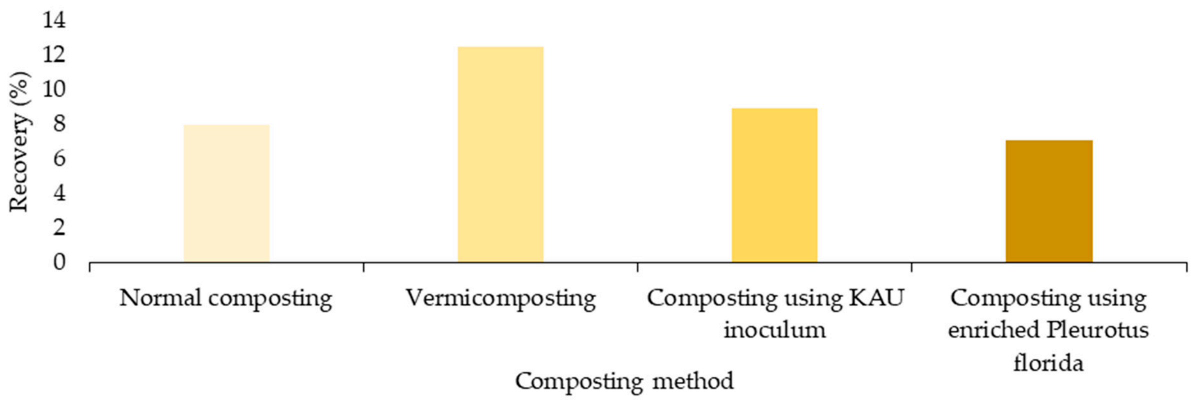

Figure 4. Effect of different composting methods on recovery % [73].

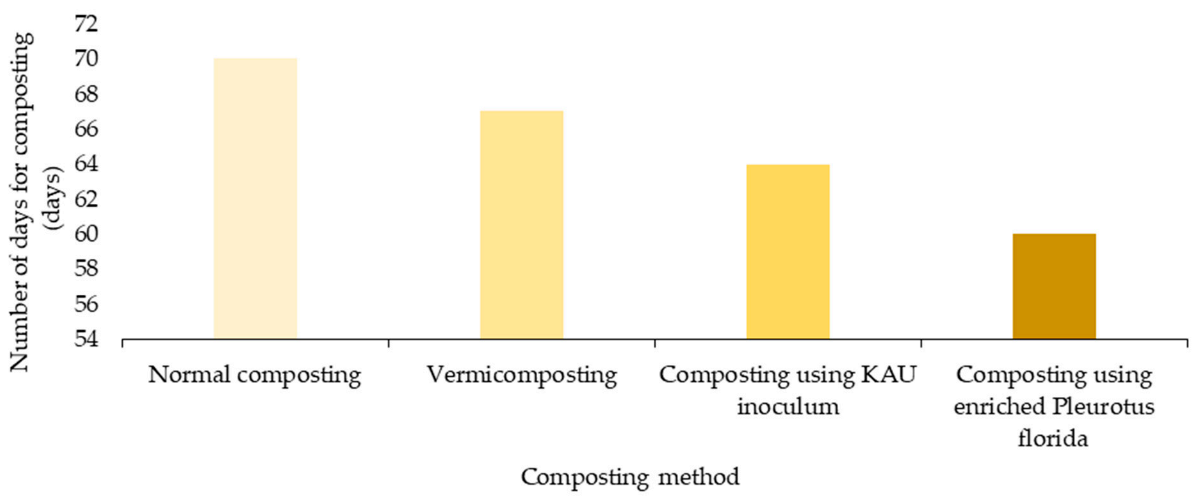

Figure 5. Effect of different composting methods on time taken for composting [73].

Different production techniques lead to different processing conditions, composting times, and micro-organism corporations with various stability, maturity, and sanitation potencies. That will result in different final products with different qualities and compositions as different nutrient contents (Figure 6).

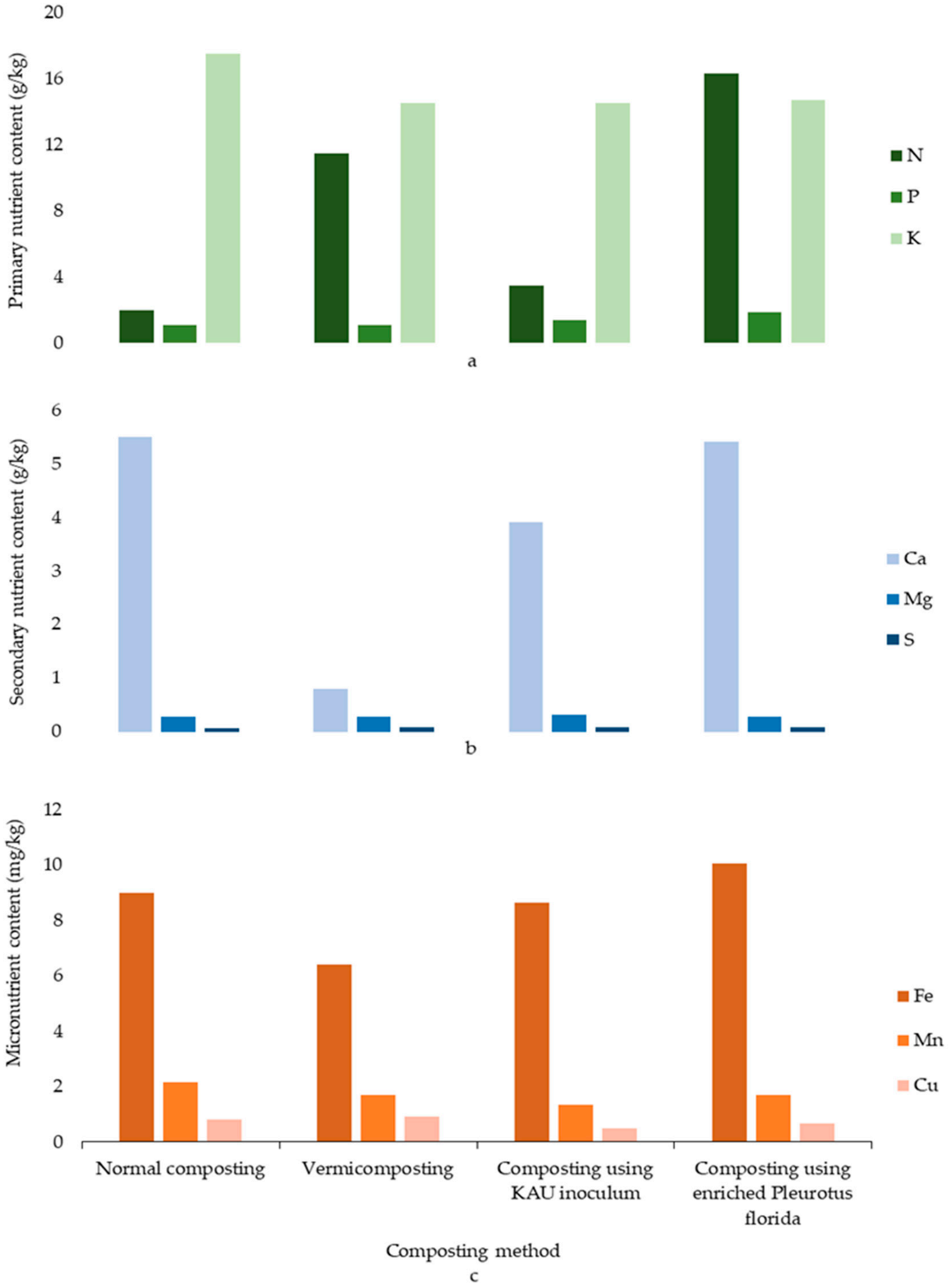

Figure 6. Effect of different composting methods on (**a**) primary, (**b**) secondary, and (**c**) micronutrient content of compost from *Limnocharis flava* (L.) Buchenau [73].

4. Steps for Producing Compost with Aquatic Weeds

Aquatic weeds should be collected at the particular stage that shows optimum plant growth. The location chosen for compost production should have shade without standing water. A foundation layer with bricks and stones, followed by a coarse sand layer (about 6–7.5 cm), can be created to maintain good drainage. Rather than applying the weed mass as is, it is better to chop the weeds into 5–10 cm long small pieces to increase the aeration and surface area. Thereby, microbial activity and decomposition rate can be enhanced. Then, the chopped weed mass can be spread on the foundation as a 30 cm thick layer. Ash, soil, organic matter, animal manure, or other materials such as municipal waste, lime, Eppawala rock phosphate, etc. can be mixed with weeds to achieve better qualities. For example, fresh cattle manure as a 10–15 L of diluted solution, and 1 L of molasses can be applied as a layer on the top of the weed pile. Followed by that, another 30 cm thick layer of weed mass can be added. This process should be revised up to receiving a $15 \times 5 \times 5^{(1/2)}$ ft compost pile. Then, the pile should be covered with black polythene. Appropriate turning and mixing steps with frequent application of water should be practised. The correct moisture content can be identified by a simple field method such as squeezing a handful of compost. Finally, the end product can be applied to the plants as a mulch or incorporated with the soil [53,63,69].

A few experiments done on composting with aquatic weeds are summarized in Table 6. Most of these experiments had been concluded with the improvement in the growth of targeted plants.

Table 6. Experiments on composting with aquatic weeds.

Name of the Aquatic Weed	Reference	Remarks
Phragmites australis, *Typha angustata*, *Azolla* sp., *Nymphoides peltatum*, *Nelumbo nucifera*, *Nymphaea* sp., and *Cerutophyllum demersum*, *Myriophyllum spicatum*	[74]	Production of Vermipellet is more effective than the production of vermicomposting from these mentioned aquatic weeds due to less disease transmission potential, lower heavy metal concentrations, minimum weed growth ability, enhanced dispersal nature, high C/N ratio, and maximum nutrient composition in vermipellets.
Ceratophyllum demursum, *Nelumbo nucifera*, *Ludwigia palustris*	[56]	Even though the parameters of compost produced with these weeds are varied, they are generally recognized as good sources for nutrient-rich vermicomposting.
Limnocharis flava	[73]	According to this research, the potential of *Limnocharis flava* for vermicomposting compared to normal composting and KAU inoculum composting was confirmed with the highest recovery percentage (the quantity of compost given by the unit amount of biomass) within 60–70 days.
Myriophyllum spp.	[68,75]	Compost made by *Myriophyllum* spp. (*M. spicatum*) had significantly higher bio-sorption capacity and ability, and thereby can be used to purify heavy metals from waste. Furthermore, herbicide application is not advisable after applying compost produced with *Myriophyllum* spp.
Eicchornia crassipis	[76]	*Eicchornia crassipis* can be transferred into nutrient-rich vermicompost materials within 60 days with the help of probiotics *Lactobacillus sporogens*.
Hydrilla verticilata	[15]	Since the whole plant is decomposable, shredding is not a must, and it can easily supply enough moisture (more than 60%) and plant growth nutrients such as P, K, Mg, and Ca.
Lagenandra toxicaria	[57]	Vermicomposting with *L. toxicaria* gives a better-quality, nutrient-rich end product than normal composting techniques. Since the end product has 6.75 dS m^{-1} of electrical conductivity, 13.21% organic carbon, 3.61% P content, 5.03% K content, and 6.12% Ca content with good microbial activities, it can be an excellent organic fertilizer source for coconut.

Table 6. *Cont.*

Name of the Aquatic Weed	Reference	Remarks
Pistia spp.	[60]	After inoculating 60–80 % of cow dung and *Eisenia fetida*, *Pistia* spp. can be transferred into odor-free, nutrient-rich (N, P, K, Cu, Zn, Fe) vermicompost.
Azolla filiculoides and *Typha latifolia*	[64]	This research justified the suitability of compost produced from these plants for agronomic usage depending on its nutritional and physical properties. Here, an autonomous, self-powered fixed bed gasifier with a gyrating cylinder bioreactor was used to reduce the time of the composting process.
Salvinia molesta	[77]	*S. molesta* has a greater potential to be an excellent vermicomposting material resulting in an ideal reduction in C: N ratio, humification index, allelopathy, and other kinds of toxicity.
Egeria densa	[78]	Composting of *Egeria densa* can be induced by inoculating microbial bio-preparations with bacteria, fungi, and actinomycetes.
Alternanthera philoxeroides	[79]	Because of the higher survival rate of these seeds, the mixing should be done properly, and the whole mixture should be uniformly subjected to a temperature higher than 55 °C over three consecutive days to avoid spreading aquatic weeds on the terrestrial composing.

5. Potential Environmental Risks Associated with the Application of Aquatic Weed Composts

Dorahy et al. summarized the environmental risk associated with applying compost prepared from aquatic weeds to terrestrial plants using different matrixes [79]. According to that, high risk was associated with the ability to survive and the spread of weeds on the land. Other than that, eutrophication of waterbodies, heavy metal accumulation, and phytotoxicity could also happen with composting. Nevertheless, the associated risks with those three were low. This will highlight the importance of having a proper composting method and ongoing management of the application. To avoid these risks, it is advisable to (1) turn and mix the compost mixture as recommended; (2) reduce the time spent stockpiling before composting, (3) increase the size of the compost pile to achieve higher internal temperature to destroy weed seeds and harmful substances [80]); (4) field application of well-processed, good-quality compost (Immature and unstable compost has a negative impact on soil fertility and seed germination) [81]); (5) avoid application of aquatic weed compost to the lands located close to water bodies; (6) maintain good site sanitary conditions; and (7) clean all machineries and tools used to handle compost, as directed [79].

6. Conclusions

Invasive aquatic weeds have been one of the most predominant threats that have many adverse effects on aquatic habitats creating negative impacts on the economy, ecology, and environment in the world. It is fast-growing with a wider range of adaptation mechanisms causing difficulties in the utilization and management of most of the water bodies. Composting is one of the best eco-friendly and sustainable ways of transferring nutrients in aquatic weeds into crop production. Short life cycle, higher biomass yield, higher plant nutrient compositions, allelopathic behaviours, and phytoremediation properties confirm their suitability as raw materials for composting. Following proper composting techniques and parameters after studying ecology and morphological features of particular aquatic weeds, most aquatic environments can be saved from soil and water pollution while enhancing crop production. Further research studies should focus more on cost–benefit analysis, legal and regulation activities, health risks, and pollutant removal of those weeds before including those weeds in the cropping cycle.

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